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UK CL (Edition J) H4F FESA FESG FESK FESX FRG FRT FRW
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(54) **Picture coding and interpolation apparatus**

(57) A picture coding apparatus operates on blocks of pixels with an orthogonal matrix transformation, 4, to generate data a the frequency content of the block, and subsequently reduces the redundancy of the data by quantisation, 6, and entropy encoding such as variable-length encoding. Additional manipulation of the picture signal, such as expansion, compression, rotation, filtering etc is achieved by multiplying the orthogonal transform matrix with another matrix within coefficients memory 5, prior to operation on the signal.

Motion compensation may be employed (Fig 3).

Also described (Fig 5) is an interpolation arrangement wherein the orthogonal matrix transformation (e.g. Discrete Cosine Transformation) is followed by an interpolation matrix transformation so as to change the number of pixels. These two matrices may be combined so that a single transformation is applied to the signal.

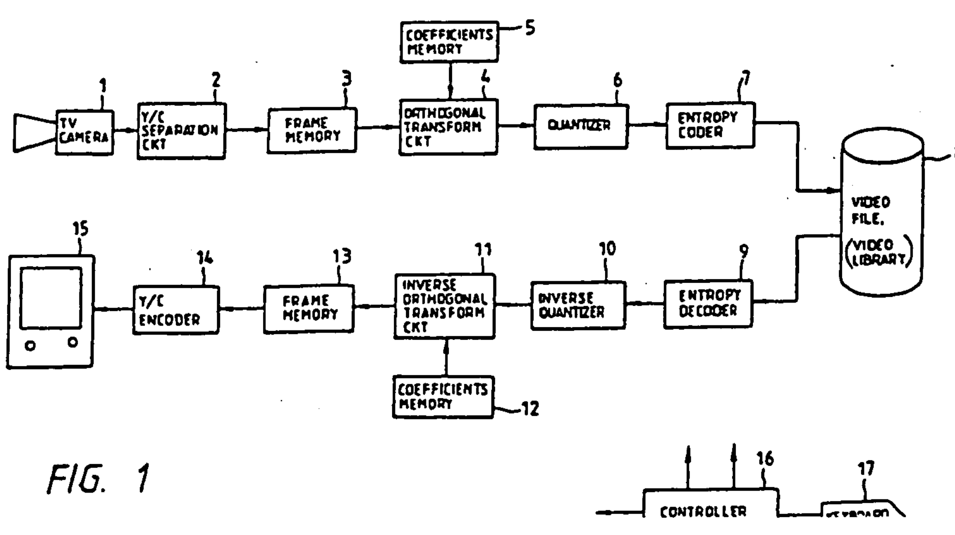

FIG. 1

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FIG. 1

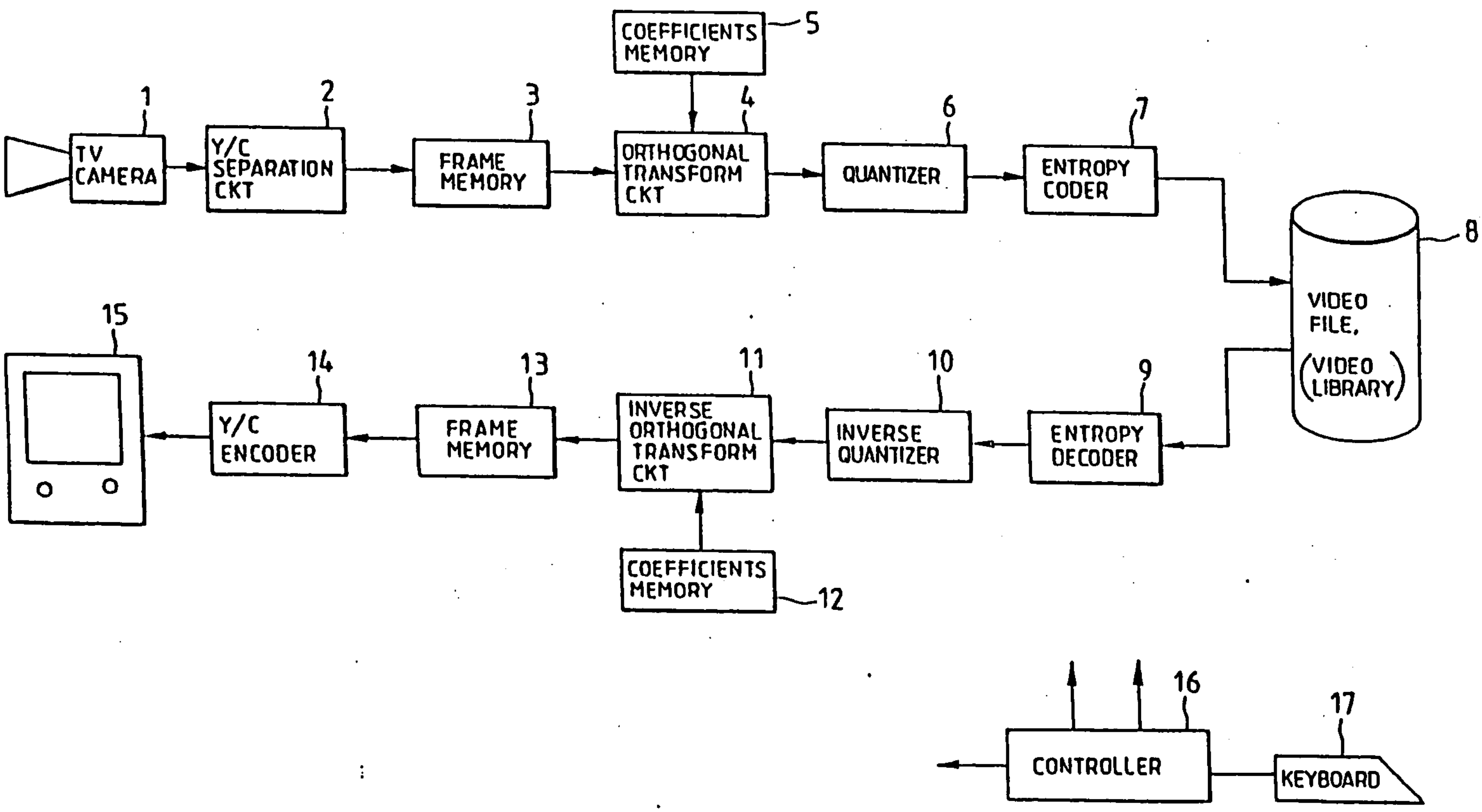


FIG. 2

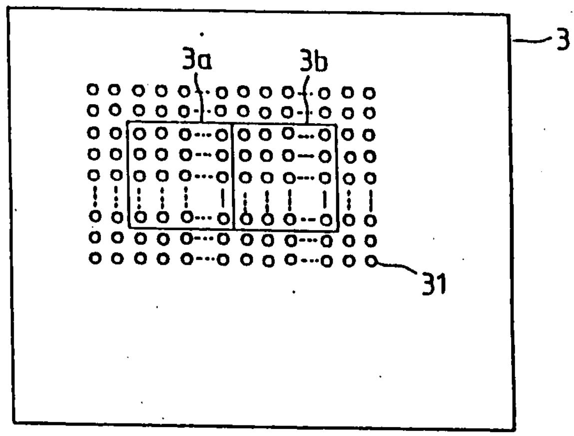


FIG. 4A

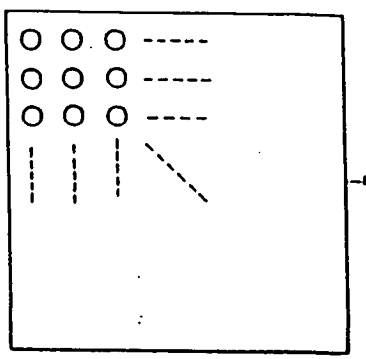


FIG. 4B

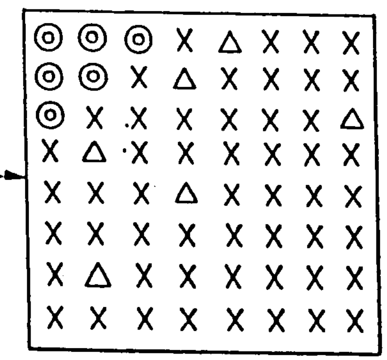


FIG. 4C

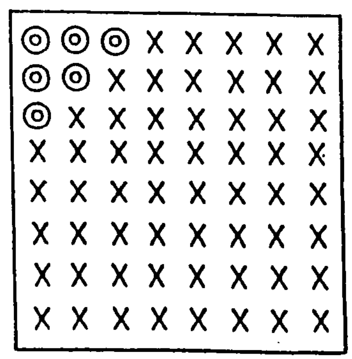


FIG. 3

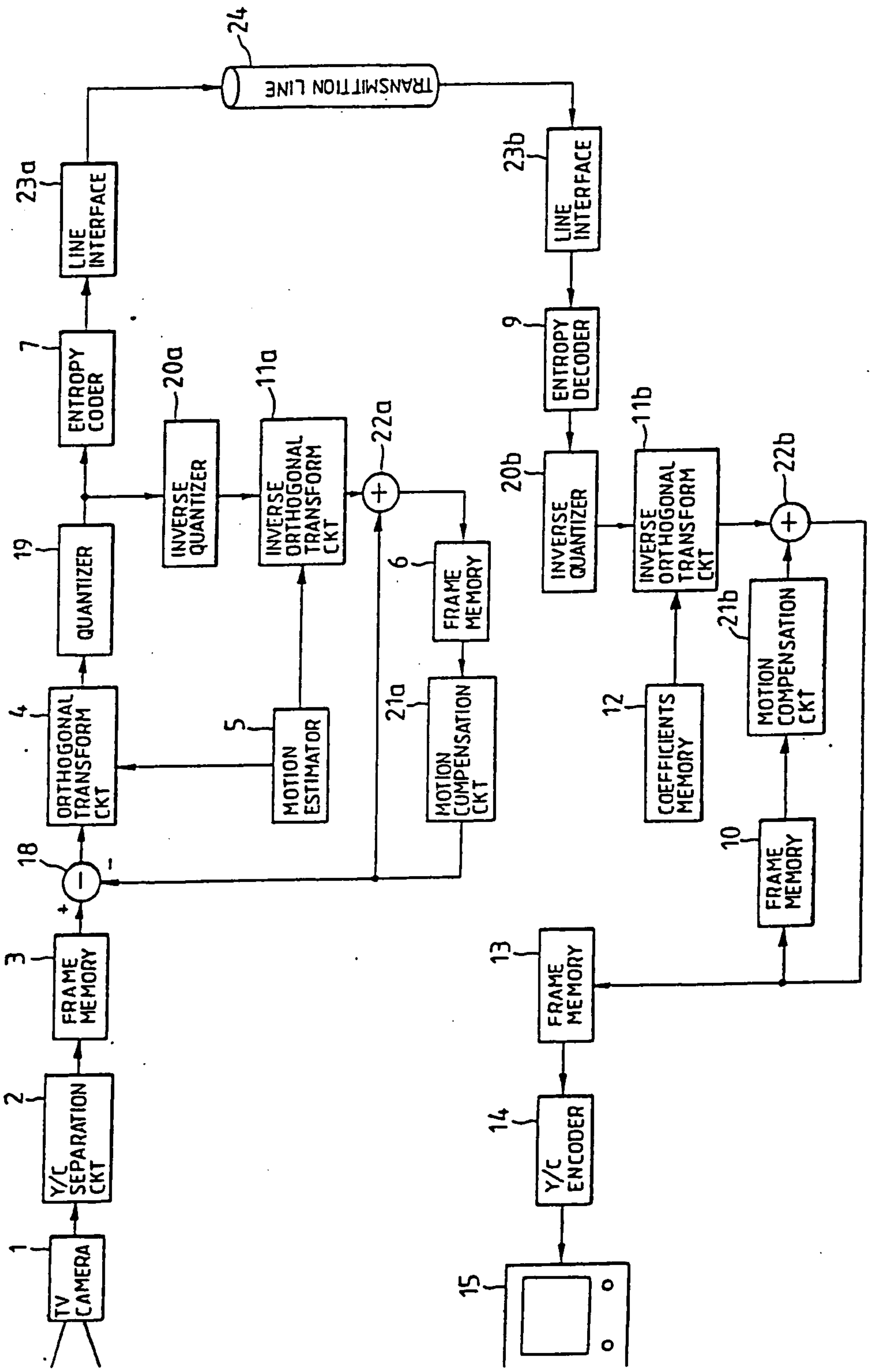

TV CAMERA
Y/C SEPARATION CKT
FRAME MEMORY
ORTHOGONAL TRANSFORM CKT
QUANTIZER
ENTROPY CODER
LINE INTERFACE
TRANSMITTION LINE
INVERSE QUANTIZER
INVERSE ORTHOGONAL TRANSFORM CKT
MOTION ESTIMATOR
FRAME MEMORY
MOTION COMPENSATION CKT
LINE INTERFACE
ENTROPY DECODER
INVERSE QUANTIZER
INVERSE ORTHOGONAL TRANSFORM CKT
COEFFICIENTS MEMORY
MOTION COMPENSATION CKT
FRAME MEMORY
FRAME MEMORY
Y/C ENCODER
1
2
3
4
5
6
7
9
10
11a
11b
12
13
14
15
18
19
20a
20b
21a
21b
22a
22b
23a
23b
24

FIG. 5

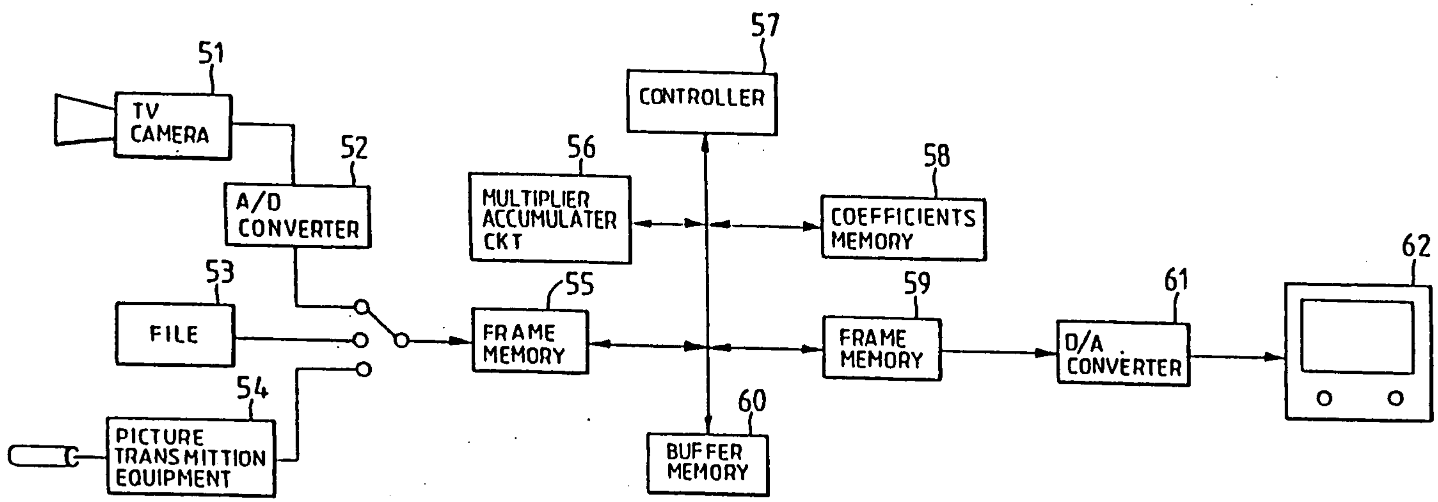
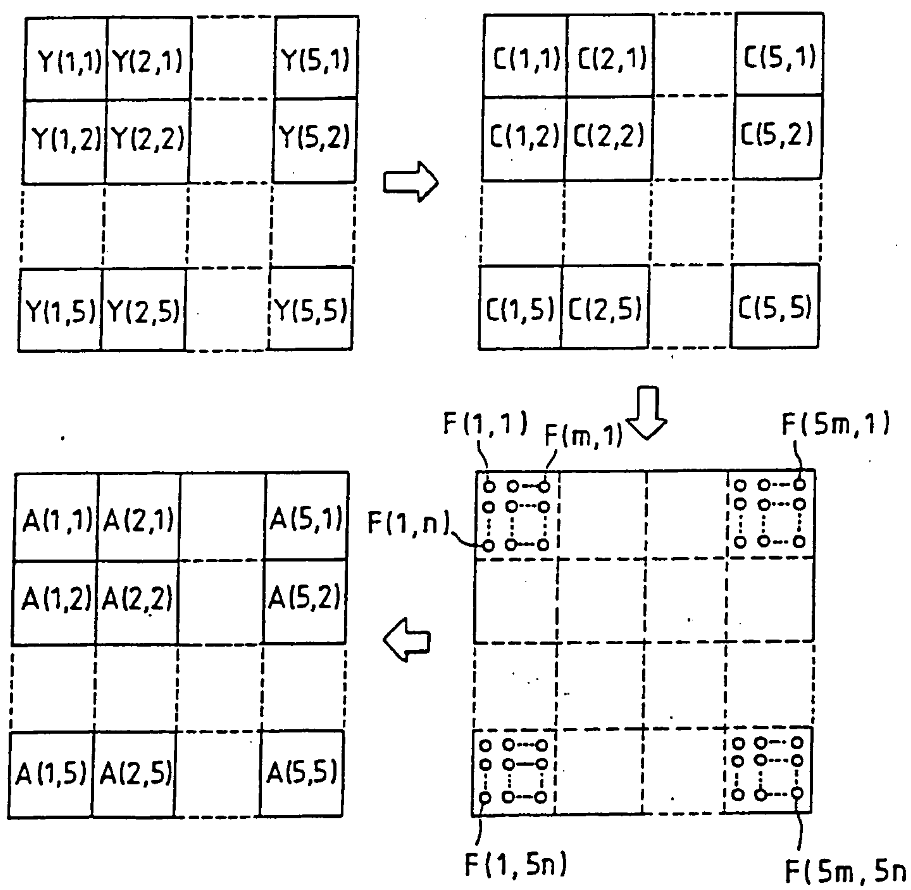

51
TV CAMERA
52
A/D CONVERTER
53
FILE
54
PICTURE TRANSMITTION EQUIPMENT
55
FRAME MEMORY
56
MULTIPLIER ACCUMULATER CKT
57
CONTROLLER
58
COEFFICIENTS MEMORY
59
FRAME MEMORY
60
BUFFER MEMORY
61
D/A CONVERTER
62

FIG. 6


Y(1,1)
Y(2,1)
Y(5,1)
Y(1,2)
Y(2,2)
Y(5,2)
Y(1,5)
Y(2,5)
Y(5,5)
C(1,1)
C(2,1)
C(5,1)
C(1,2)
C(2,2)
C(5,2)
C(1,5)
C(2,5)
C(5,5)
F(1,1)
F(m,1)
F(5m,1)
F(1,n)
F(1,5n)
F(5m,5n)
A(1,1)
A(2,1)
A(5,1)
A(1,2)
A(2,2)
A(5,2)
A(1,5)
A(2,5)
A(5,5)

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"A picture coding apparatus and interpolation circuit"

The present invention relates to a picture signal processor in which a picture signal (either a still picture or a motion picture) is coded in order to transmit or file it at a high efficiency or in which a picture signal spatially sampled is converted into a picture of different resolution.

Previous known apparatus for coding picture signals have been used for transmitting or filing the picture signals.

Among coding systems employed in the picture signal coders, one which is very excellent in points of the coding efficiency and the picture quality, is a block coding system which adopts an orthogonal transform.

This system utilizes the fact that, when a signal within a block has been transformed into two-dimensional frequency components, electric power concentrates near a component of low order (for example, a D.C. term corresponding to a mean value). As the methods of the transform, there are the DCT (Discrete Cosine Transform), etc. (refer to, for example, N. Ahmed, et al; "Discrete Cosine Transform", IEEE Trans. Comput., vol. C-23, 1974-1).

Such a still picture filing apparatus or motion picture transmitting apparatus employing the orthogonal transform has had various problems which are referred to below.

For example, in picture resolution conversion including

manipulation process as expansion, compression or rotation has been generally performed in a picture-frame unit.

More specifically, the impulse response of an interpolation filter corresponding to the picture conversion is found, and the convolution between the impulse response and an input picture signal is taken. Since, however, this processing method results in the form of a two-dimensional convolution, it involves a large number of operations and can only be satisfactorily achieved by means of a high-speed processing circuit which consists of a large number of multiplier units.

Furthermore, it is difficult to share a frame memory for storing an original picture and a picture as the processed result thereof, and moreover a frame memory for the interpolation process needs to be separately added. This has the disadvantage that the size of the circuit for the processing method greatly increases.

An interpolation circuit for use with a prior-art picture signal processor utilizes a method wherein a two-dimensional picture signal is multiplied by two-dimensional operators so as to accumulate the products (a method based on the so-called two-dimensional convolution).

This interpolation method involves a small number of calculations and has been effective as a general interpolation method:

(a) in the case where the two-dimensional operators are comparatively few in number, for example, 3 x 3, or

(b) in the case where the relationship between the

position of a pixel to be obtained by the interpolation and the positions of the pixels of the original picture is regular (for example, the case where the former pixel lies at the middle point of the latter pixels).

The method, however, has resulted in an increase in the number of calculations and enlargement in the size of the circuit.

(a) in the case where the two-dimensional operators are relatively large in number, for example, where a block average is smoothed and then displayed in the progressive coding of a picture, or

(b) in the case where the pixel to be obtained by the interpolation and the pixels of the original picture are not in a simple positional relationship such as the middle point, as in the conversion between PAL and NTSC signals.

It is an object of the present invention to provide a picture signal coder which realizes the picture resolution conversion and the conversion of image manipulation processing at a very high speed and without the addition of any special circuit.

It is another object of the present invention to provide a picture signal interpolator which is capable of interpolation processing with a comparatively few number of calculations.

In a first aspect of the present invention the conversion process of a picture signal is performed in block unit, not in frame unit, in order to raise the speed of the process. In addition to the orthogonal transform matrix

stated previously, the products between this orthogonal transform matrix and matrices which realize the picture resolution conversation, the image manipulation process such as expansion, compression and rotation, and various kinds of linear filtering are provided in a coefficient memory as new transform matrices, which are properly changed-over in accordance with the content of the conversion process in order to perform an orthogonal transform or an inverse orthogonal transform.

In this manner, in the block coding apparatus which employs the orthogonal transform, the products between the inverse orthogonal matrix and the matrices for image manipulation and filtering processing are adopted as new inverse transform matrices, whereby the above processes can be realized very fast and easily. Further, in the communications of a motion picture, the values of orthogonal transform coefficients which are not transmitted are reduced by the use of the filtering process, whereby the elimination of a block distortion harmful in the picture quality and the enhancement of the transmission efficiency can be realized.

In a second aspect of the present invention an original picture signal is once converted into two-dimensional frequency components by the use of the orthogonal transform matrix, whereupon they are converted into a spatial area again by the use of an interpolating matrix, whereby the amount of calculations of the interpolation process is reduced. Further, the products between the orthogonal transform matrix and the interpolating matrix are provided

in a transform constant memory as a new transform matrix beforehand, and they are properly changed-over in accordance with the position of a pixel to be interpolated or the kind of the interpolation, whereby a higher processing speed can be realized.

In this manner, the picture signal is once converted into the two-dimensional spatial frequency components by the orthogonal transform, and they are subsequently converted into the spatial area again by the inverse orthogonal transform, whereby the interpolation process of a picture can be realized very flexibly and simply. Further, the products of the matrices for the orthogonal transform as well as the inverse orthogonal transform and any desired linear transform are calculated and written into the transform constant memory beforehand, and they are properly selected and used, whereby very fast and simple interpolating and filtering processes become possible. Further, in the communication of a picture employing the orthogonal transform, block averages are first transmitted, and differences from a curved surface obtained by interpolations from the averages are transmitted, whereby the transmitting period of time can be shortened. At this time the above differences are the differences of orthogonal transform coefficients themselves, and they can be obtained very simply without requiring any complicated process.

The present invention will now be described in greater detail by way of examples with reference to the accompanying drawings, wherein:-

Fig. 1 is a diagram showing the arrangement of a filing apparatus for still pictures which has image manipulation functions such as expansion, compression and rotation;

Fig. 2 is a conceptual diagram showing the positional relationship between the frame of a picture and blocks in the case of performing an orthogonal transform;

Fig. 3 is a diagram showing the arrangement of a motion picture transmitting apparatus;

Figs. 4A to 4C are diagrams showing the relationship between the orthogonal transform coefficients and filtering process of a motion picture coding apparatus;

Fig. 5 is a diagram showing an embodiment of a picture interpolation circuit according to the present invention; and

Fig. 6 is a conceptual diagram showing the relationship between the D.C. values and interpolated pictures of a picture divided into blocks.

Firstly, the process of converting a picture signal in a transmitting or recording mode will be explained.

Referring to Fig. 1, a picture signal taken by a television camera 1 is spatially sampled and is thereafter separated by a Y/C separation circuit 2 into a luminance signal (Y) and colour-difference signals (C1, C2), which are respectively written into a frame memory 3. The contents of this frame memory are read out every block, e.g., 3a or 3b in which pixels 31 are put together as illustrated in Fig. 2, and they are converted by an orthogonal transform circuit 4 into coefficients which

correspond to frequency components. On this occasion, the values of a coefficient matrix (for example, DCT) to be used for the conversion are fetched from a coefficient memory 5. The coefficients after the conversion are quantized by a quantizer 6, and the quantized coefficients are transferred to an entropy coder 7 and are coded into signals with redundancy removed, which are recorded in a video file 8.

The content of the conversion which is performed by the orthogonal transform circuit 4, will now be described.

When the divided parts of the picture signal are expressed by, for example, a matrix of 8 x 8 elements; D(8, 8), the following formula holds:

$$C = T \, . \, D \, . \, T^{-1}$$

wherein T (T^{-1}) denotes an orthogonal transform matrix, which becomes the following equation (1) in the case of the DCT:

$$T_{ij} = \tfrac{1}{2} \, [K_i \, . \, \cos \{i(j + \tfrac{1}{2}) \pi/8\}] \quad (i, j = 0, 7) \qquad \ldots(1)$$

where $K_i = 1/\sqrt{2}$ for $i + 0$, and

$K_i = 1$ for $i \neq 0$.

As the result of the conversion, the coefficient matrix C(i, j) corresponding to the frequency components within the block is generated. In this case C(0, 0) is a D.C. coefficient corresponding to the average value of the block, and the coefficients are of higher spatial frequencies as <u>i</u> and <u>j</u> increase.

In general pictures, significant coefficients concentrate on coefficients of comparatively low orders, so

that the removal of redundancy is permitted by the assignments of quantization and variable-length coding utilizing this property.

On the other hand, in a reproducing mode, the variable-length codes read out of the video file 8 are decoded by an entropy decoder 9 into the orthogonal transform coefficients, which are passed via an inverse quantizer 10 and then inverse-transformed into the original picture signal every block by an inverse orthogonal transform circuit 11. On this occasion, a coefficient matrix to be used for the inverse transform is fetched from a coefficient memory 12. The reproduced picture signal is passed via a frame memory 13 and has a luminance signal and colour-difference signals composed by an encoder 14, whereupon the resulting picture is displayed on a monitor television set 15.

The above circuit arrangement is controlled by a controller 16 in accordance with the contents of commands given from a keyboard 17.

The content of the conversion which is performed by the inverse orthogonal transform circuit 11 will now be described.

In an ordinary case where any image manipulation function is not used, the picture within the block is subjected to the following transform:

$$D = T^{-1} \cdot C \cdot T \qquad \ldots(2)$$

wherein the values of the DCT matrices T and T^{-1} are fetched from the coefficient memory 12.

On the other hand, in the case where the picture within the block is processed by any image manipulation function, the following transform is carried out:

$$D = (L \cdot T^{-1}) \cdot C \cdot (T \cdot R) \qquad \ldots(3)$$

wherein L and R denote matrices each having 8 x 8 elements, and the products between each of them and the corresponding one of T and T^{-1} become a matrix in the same form. Also the values of the two transform matrices $(L \cdot T^{-1})$ and $(T \cdot R)$ are fetched from the coefficient memory 12 in accordance with signals from the controller 16, and the processes of the image manipulation and the inverse transform are simultaneously performed by the inverse orthogonal transform circuit 11.

The contents of the matrices L and R can be expressed depending upon the kinds of the image manipulation, as indicated below by way of examples:

(1) The case of Horizontal Inversion:

$L = E\,0, \quad R = E\,90$

where E 0; unit matrix, and

$$E\,9\,0 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(2) The case of Vertical Inversion:

$L = E\,90, \quad R = E\,0$

(3) The case of 90° Right Turn:

$C \longrightarrow {}^{t}C$ (transposition), and

$L = E\,0, \quad R = E\,90$

(4) The case of 90° Left Turn:

$C \longrightarrow {}^{t}C$ (transposition), and

$L = E\,90, \quad R = E\,0$

(5) The case of 180° Rotation:

$L = E\,90, \quad R = E\,90$

(6) The case of Expansion (in Horizontal Direction):

$L = E\,0, \quad R = MH$

For doubling a left half,

$$MH = \begin{bmatrix} 1 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/2 & 1 & 1/2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/2 & 1 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/2 & 1 & 1/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1/2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

(7) The case of Expansion (in Vertical Direction):

$L = MV, \quad R = E\,0$

For doubling an upper half,

$$MV=\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1/2 & 1/2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1/2 & 1/2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/2 & 1/2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/2 & 1/2 & 0 & 0 & 0 \end{bmatrix}$$

(8) The case of Compression:

When an expansion matrix consisting of the coefficient matrices C 11, C 12, C 21 and C 22 of four adjacent blocks:

$$C = \begin{bmatrix} C\,11 & C\,12 \\ C\,21 & C\,22 \end{bmatrix}$$

is compressed to ½,

$$\begin{bmatrix} D\,11 & D\,12 \\ D\,21 & D\,22 \end{bmatrix} = \begin{bmatrix} T^{-1} & 0 \\ 0 & T^{-1} \end{bmatrix} \begin{bmatrix} C\,11 & C\,12 \\ C\,21 & C\,22 \end{bmatrix} \begin{bmatrix} T & 0 \\ 0 & T \end{bmatrix}$$

where the calculations of even-numbered (odd-numbered) rows and columns are not executed.

(9) The case of Low Pass Filtering (LPF):

L = KL, R = KR

where

$$KL = \begin{bmatrix} 1-a & a & 0 & 0 & 0 & 0 & 0 & 0 \\ a & 1-2a & a & 0 & 0 & 0 & 0 & 0 \\ 0 & a & 1-2a & a & 0 & 0 & 0 & 0 \\ 0 & 0 & a & 1-2a & a & 0 & 0 & 0 \\ 0 & 0 & 0 & a & 1-2a & a & 0 & 0 \\ 0 & 0 & 0 & 0 & a & 1-2a & a & 0 \\ 0 & 0 & 0 & 0 & 0 & a & 1-2a & a \\ 0 & 0 & 0 & 0 & 0 & 0 & a & 1-a \end{bmatrix}$$

$$KR = \begin{bmatrix} 1-b & b & 0 & 0 & 0 & 0 & 0 & 0 \\ b & 1-2b & b & 0 & 0 & 0 & 0 & 0 \\ 0 & b & 1-2b & b & 0 & 0 & 0 & 0 \\ 0 & 0 & b & 1-2b & b & 0 & 0 & 0 \\ 0 & 0 & 0 & b & 1-2b & b & 0 & 0 \\ 0 & 0 & 0 & 0 & b & 1-2b & b & 0 \\ 0 & 0 & 0 & 0 & 0 & b & 1-2b & b \\ 0 & 0 & 0 & 0 & 0 & 0 & b & 1-b \end{bmatrix}$$

In this case, any desired low-pass characteristics can be bestowed by changing the values $\underline{a}$ and $\underline{b}$ (subject to $0 \leqq a, b \leqq 0.5$).

Although, in the above, the various examples of the image manipulation and the filtering have been described, it is to be understood that similar effects are attained also for processes of still higher degree and complicated combinations thereof.

Although in the above examples, the matrices L and R have been assumed to consist of 8 x 8 elements which have

the same form as that of the picture D or the transform coefficients C, it is possible, however, that the picture D to be extracted is expanded into, for example, 12 x 12 elements on the sending side, while the matrices L and R are respectively set at 8 x 12 elements and 12 x 8 elements. On this occasion, the following formula (4) holds:

$$C = T \cdot L \cdot D \cdot R \cdot T^{-1} \qquad \ldots(4)$$

In this manner, regarding any desired linear transform which is expressed by a matrix, the products between the matrix and an inverse orthogonal transform matrix are read out of a memory circuit, and they are multiplied from both the sides of the coefficient matrix, whereby the conversion of a picture and the inverse orthogonal transform can be simultaneously performed, and the operating period of time can be reduced to a half or less.

Circuits required for the processing stated above are only the memory circuit for storing the matrices as mentioned above and some control circuits for changing-over the matrices in accordance with the kinds of the transforms, and they can be realized very simply. In addition, a system which rewrites the contents of the memory circuit adaptively by the use of a microprocessor can be readily realized.

Next, a second embodiment of the present invention will be described with reference to Fig. 3 and Figs 4A - 4C in connection with a motion-compensated interframe coding equipment of low bit rate.

As in the first embodiment, the output of a television

camera 1 is separated by a Y/C separation circuit 2 into luminance and colour-difference signals, which are respectively written into a frame memory 3. The picture signal is divided into blocks each having 8 x 8 pixels, and the difference thereof from the signal of a transmitted frame is input to an orthogonal transform circuit 4 by a subtracter 18. On this occasion, the motion vector between the frames is measured so that the difference may be reduced (motion-compensated interframe prediction).

In the orthogonal transform circuit 4, the products between a transform matrix and a matrix having low-pass characteristics are read out of a motion estimator or coefficient memory 5 as stated in the first embodiment. The low-pass characteristics are adaptively controlled in accordance with the number of transmission frames. The coefficients after the conversion are passed through a quantizer 19 and have redundancy removed by an entropy coder 7, and the resulting codes are delivered to a transmission line 24 via a line interface 23a.

In addition, the output of the quantizer 19 is coded into an interframe difference signal by an inverse quantizer 20a as well as an inverse orthogonal transform circuit 11a, the difference signal is added with a motion vector-compensated transmitted frame signal by an adder 22a, and the resulting signal is written into a frame memory 6 as a new frame signal. By means of a motion compensation circuit 21a, the output of the frame memory 6 becomes a reference picture which is compared with a frame signal to be

subsequently transmitted.

On the other hand, the signal of the transmission line 24 is decoded into an orthogonal transform coefficient by a line interface 23b as well as an entropy decoder 9, and the coefficient is transformed into an interframe difference signal by an inverse quantizer 20b as well as an inverse orthogonal transform circuit 11b. As in the case of the sending side, this interframe difference signal is added with a motion vector-compensated transmitted frame signal by an added 22b, and the resulting signal is written into frame memories 10 and 13 as a new frame signal. This signal is passed through a Y/C encoder 14, and is displayed on a monitor TV set 15.

On this occasion, the various circuits including a motion compensation circuit 21b are controlled so that the contents of the frame memory 10 may agree with those of the frame memory 6 on the sending side.

Incidentally, in the case of an inverse orthogonal transform, both the sending and receiving sides employ an ordinary inverse transform matrix in consideration of the compatibility (but it is also possible to execute various kinds of image manipulation processes and filtering processes described in the first embodiment).

Next, a process for eliminating a block distortion will be described with reference to Figs. 4A to 4C.

In general, when all coefficients subjected to the orthogonal transform are transmitted, the block distortion hardly poses a problem. It is sometimes the case, however,

that significant coefficients of comparatively high orders fail to be transmitted due to the security of the number of transmission frames. By way of example, when pixel signals shown in Fig. 4A are subjected to the orthogonal transform, the transformed coefficients become as shown in Fig. 4B. Here, marks ◎ denote significant coefficients which are transmitted, marks x denote insignificant coefficients which are not transmitted, and marks △ denote coefficients which are significant but which cannot be transmitted. On the receiving side, the values of the untransmitted coefficients are decoded as zero at this time, so that a level difference arises between blocks under the influence of the coefficients indicated by the marks △ and appears as an obstacle in the picture quality.

In the present invention, in order to prevent such degradations in the picture quality, when the number of transmission frames is secured, the orthogonal transform is performed in the way that the products between the orthogonal transform matrix and the matrix having the low-pass characteristics are fetched from the coefficient memory 5. Since the comparatively high frequency components of the picture are removed by the low-pass filtering, the values of the untransmitted coefficients become small as illustrated in Fig. 4C.

As a result, the picture quality degradations ascribable to the block distortion can be eliminated or relieved very effectively. It is also possible to control the number of transmission frames in such a way that the

filtering characteristics are adaptively controlled in accordance with the picture to-be-transmitted.

Since the above filtering process is performed simultaneously with the orthogonal transform, it is very fast. It can be readily realized merely by increasing the area of the coefficient memory.

Moreover, coefficients which are hardly problematic in the picture quality even when not transmitted are uniquely determined by the filtering characteristics. By coding the characteristics and transmitting the codes, therefore, the transmission of the invalid coefficients can be omitted, and the enhancement of the transmission efficiency can be achieved.

In this embodiment, the multiplier-accumulator circuits are employed for the operations. However, in a case where the processing period of time has some margin, signal processors can also be utilized.

[Embodiment 3]

The third embodiment of the present invention will now be described with reference to Fig. 5.

The circuit arrangement shown in Fig. 5 converts an original picture of $\underline{m}$ x $\underline{n}$ pixels into an interpolated picture of M x N pixels. A digital picture signal which has been accepted from a television camera 51 and an A/D converter 52, from a still picture file 53 or from a still picture transmission equipment 54 is once written into a frame memory 55. Signals of $\underline{m}$ x $\underline{n}$ pixels; V(i, j) (i = 1, 2, ... m) (j = 1, 2, ... n) are read out of the frame memory

55, and they are subjected by a multiplier-accumulator circuit 56 to multiplying accumulation operations with signals read out of a coefficient or transform constant memory 58, thereby to be transformed into coefficients corresponding to frequency components; C(i, j) (i = 1, 2, ... m) (j = 1, 2, ... n). This transform is a linear transform, and is expressed as follows by the use of transform matrices D1(i, j) (i, j = 1, 2, ... n) and D2(i, j) (i, j = 1, 2, ... m):

$$C = D1 \cdot Y \cdot D2 \qquad \ldots(5)$$

Although transform matrices include those of KL transform, Hadamard transform, etc., DCT (Discrete Cosine Transform) of comparatively easy operations and excellent characteristics is used. In case of the DCT, the matrices D1 and D2 become as follows:

$$D1(i, j) = \sqrt{2/n}\,[K_j \cdot \cos\{(i - \tfrac{1}{2})(j - 1)\pi/n\}]$$
$$(i, j = 1, 2, \ldots n) \qquad \ldots(6)$$

$$D2(j, i) = \sqrt{2/m}\,[K_j \cdot \cos\{(i - \tfrac{1}{2})(j - 1)\pi/m\}]$$
$$(i, j = 1, 2, \ldots m) \qquad \ldots(7)$$

where $K_j = 1/\sqrt{2}$ for j = 1, and

$K_j = 1$ for $j \neq 1$

The matrices D1 and D2 are normalized orthogonal transform matrices (unitary matrices), and the products thereof form a unit matrix at m = n.

The coefficients transformed by the multiplier-accumulator circuit 56; C(i, j) (i = 1, 2, ... m) (j = 1, 2, ... n) are components which correspond to a kind of spatial frequencies. C(1, 1), for example, is a D.C.

coefficient corresponding to the average value of a block, and the coefficients are of higher spatial frequencies as i and j increase.

These coefficients are once stored in a buffer memory 60.

Subsequently, matrices for an interpolation process are read out of the coefficient memory 58, and the multiplications thereof with the above transform coefficients are executed by the multiplier-accumulator circuit 56, whereby an interpolated picture F is generated. This interpolated picture F is written into a frame memory 59, and is displayed on a monitor (display unit) 62 via a D.A converter 61. These circuits are controlled by a controller 57.

The following formula (8) holds for the transform stated above:

$$F = H1 \cdot C \cdot H2 \qquad \ldots(8)$$

In addition, H1 and H2 become as follows:

$$H1(j, i) = \sqrt{2/N}\ [K_j \cdot \cos\{(i - \tfrac{1}{2})(j - 1)\pi/N\}]$$
$$(i = 1, 2, \ldots N)\ (j = 1, 2, \ldots n) \qquad \ldots(9)$$
$$H2(i, j) = \sqrt{2/M}\ [K_j \cdot \cos\{(i - \tfrac{1}{2})(j - 1)\pi/M\}]$$
$$(i = 1, 2, \ldots N)\ (j = 1, 2, \ldots m) \qquad \ldots(10)$$

where $K_j = 1/\sqrt{2}$ for $j = 1$, and

$K_j = 1$ for $j \neq 1$

Owing to the above operations, the original picture of $m \times n$ pixels is converted into the interpolated picture of $M \times N$ pixels by the DCT matrices D1, D2 and the interpolation matrices H1, H2.

Although, in the above, the process for obtaining the orthogonal transform coefficients and the process for generating the interpolated picture on the basis of these coefficients have been described as two separate stages, they are realized by a single process in this embodiment. A detailed explanation of the single process will now be given.

When equation (5) is substituted into equation (6), the following formula is obtained:

$$\begin{aligned} F &= H1 \cdot D1 \cdot Y \cdot D2 \quad H2 \\ &= (H1 \quad D1) \cdot Y \cdot (D2 \quad H2) \qquad \ldots(11) \end{aligned}$$

wherein $(H1 \cdot D1)$ and $(D2 \cdot H2)$ denote matrices of $(n \times N)$ and $(M \times m)$, respectively, and they can be uniquely obtained beforehand irrespective of the contents of the original picture when the positional relations between the original picture and pixels to be interpolated are determined.

Accordingly, the contents of these matrices are previously written into the coefficient memory 58, whereby the interpolation process can be realized by very fast and simple operations.

It should be noted that in the case where no interpolation is performed ($M = m$, $N = n$), the matrices $(H1 \cdot D1)$ and $(D2 \cdot H2)$ become the unit of $(\underline{n} \times \underline{n})$ and $(\underline{m} \times \underline{m})$, respectively, and the original picture Y is reproduced as it is.

There will be explained the relationship between the orthogonal transform coefficients and the picture in the above interpolation process.

When the transform coefficients of equation (5) are brought into correspondence with original picture areas, they are expressed as cosine curved surfaces corresponding to the orders thereof. For example, the coefficient C(2, 1) becomes a curved surface which varies in a horizontal direction at a half of the cosine cycle. This curved surface is continuous, and the values of any desired points lying thereon are significant for the interpolated picture.

Accordingly, although i and j have been defined as integers in equation (9), they need not always be the integers. In the case where interpolation points are at unequal intervals, any desired real numbers can also be employed.

Further, besides the interpolation process stated above, the filing process etc. of the picture can be simultaneously realized.

By way of example, any desired matrices W and W' are multiplied from both the sides of the original picture Y or the interpolation picture F, whereby low-pass and other filtering processes can be realized. More specifically, instead of the matrices (H1 . D1) and (D2 . H2) in equation (11), matrices (W . H1 . D1) and (D2 . H2 . W), (H1 . D1 . W) and (W . D2 . H2), or (H1 . W . D1) and (D2 . W . H2) are written into the coefficient memory 58 beforehand, and the multiplications thereof with the original picture Y are executed, whereby the speed of the operations can be readily raised.

In addition, transform constants are sometimes

arranged very regularly in these matrices, and a high-speed operating method called "FFT" is also applicable.

Although, in the above, the several examples of the interpolation and filtering of pictures have been described, it is to be understood that similar effects are attained also for processes of still higher degree and complicated combinations thereof.

Circuits required for such processes are only the memory circuit for storing the matrices stated above and some control circuits for changing-over the matrices in accordance with the kinds of the transforms, and they can be realized very simply.

Further, it has been described above the picture signals accepted from the television camera, the still picture file and the still picture transmission equipment are handled. In this regard, in the transmission equipment fcr the still picture or a transmission equipment for a motion picture, the picture is divided into blocks, the transform such as DCT is performed every block, and the transformed coefficients are entropy-coded and then transmitted. Accordingly, in the case where the coefficients are inverse-transformed on the receiving side, circuits therefor and arithmetic circuits indicated by equation (8) of this embodiment can also be shared.

Besides, the interpolation process described in this embodiment can also be realized using digital signals processors which have multiplying accumulation operation functions of very high speed.

Further, using these processors, a system in which the contents of the memory circuit are adaptively rewritten can be realized with ease.

In this manner, regarding any desired linear transform which is expressed by a matrix, the products between the matrix and an inverse orthogonal transform matrix are read out of a memory circuit, and they are multiplied from both the sides of the coefficient matrix, whereby the conversion of a picture and the inverse orthogonal transform can be simultaneously performed, and the operating period of time can be shortened to a half or less.

The fourth embodiment of the present invention will now be described with reference to Fig. 6.

The third embodiment has been described as to the method of obtaining the interpolated picture of the M x N pixels interpolated from the original picture of the $\underline{m}$ x $\underline{n}$ pixels. However, when the interpolation process is performed using the average of, for example $\underline{m}$ x $\underline{n}$ blocks left intact, the average values of the individual blocks are not always ensured.

In this embodiment, therefore, an interpolation method in which the D.C. values (average values) of a picture divided into blocks are kept will now be described.

An example of interpolation which employs the average values of a block to be subjected to an interpolation process and the surrounding 24 blocks is illustrated in Fig. 6.

Now, when an original picture Y(5, 5) consisting of 5 x

5 blocks is subjected to the orthogonal transform by the method DCT stated in the third embodiment, 5 x 5 transform coefficients C(5, 5) can be found, and an interpolated picture F(M, N) can be obtained from the coefficients by the use of equation (8).

Assuming here that each of the blocks is configured of m x n pixels, the following holds:

$$F = H1 \cdot c \cdot H2$$

$$M = 1, 2, \ldots 5m, \quad N = 1, 2, \ldots 5n$$

where H1 and H2 denote the respective matrices stipulated by equation (9) and equation(10).

That is, the interpolated picture F(M, N) can be expressed using the 25 unknown transform variables C(i, j) (i = 1, 2, ... 5) (j = 1, 2, ... 5).

Accordingly, letting A(i, j) (i = 1, 2, ... 5) (j = 1, 2, ... 5) denote the averages of the respective blocks, the following formula holds:

$$A(i, j) = \sum_{k,l} F(i + k, j + l) \qquad \ldots(12)$$

Thus, 25 linear equations whose number is equal to that of the unknown variables are generated, and the aforementioned transform coefficients C(i, j) can be evaluated by solving the simultaneous equations.

That is, the following equations hold:

$$a = W \cdot c \qquad \ldots(13)$$

$$c = W \cdot a \qquad \ldots(14)$$

where c and a denote vectors of 25 terms into which the respective matrices C and A of 5 x 5 elements are rearrayed to be undimensional. Since the matrix W does not depend

upon the original picture, it is computed beforehand and is written into the transform constant memory 58, whereby the interpolation process can be realized using a method similar to that of the third embodiment.

That is, the matrix C is determined from the vector $\underline{c}$, and the interpolated picture F(M, N) in which the block averages are kept can be obtained using equation (8).

Although, in the above description, the original picture Y(5, 5) composed of the 5 x 5 blocks has been referred to, it is to be understood that the original picture can be expanded to any desired number of blocks.

Furthermore, as in the third embodiment, any of the low-pass and other filtering processes can be simultaneously realized.

Moreover, regarding the motion picture or still picture transmission equipment wherein the orthogonal transform such as DCT is performed every block, differences from the interpolation pixels F(M, N) as evaluated from the D.C. values are transmitted, whereby the transmission period of time can be shortened. The reason is that, in the periphery of the block, deviations from the average value become large. More specifically, when the parts to be transmitted in the interpolated picture:

$$F'(K, L) \quad (K = 1, 2, \ldots m) \quad (L = 1, 2, \ldots n)$$

are extracted and are subjected to the orthogonal transform by the use of equation (5), the following formula holds:

$$\begin{aligned} C' &= D1 \cdot F \cdot F' \cdot D2 \\ &= (D1 \cdot H1) \cdot C \cdot (H2 \cdot D2) \qquad \ldots(15) \end{aligned}$$

wherein differences from interpolated pixels F' (M, N) as obtained from the D.C values are expressed as differences also in the area of orthogonal transform coefficients C'. Accordingly, the method of transmitting the differences between the coefficients C' and the coefficients obtained by the orthogonal transforms of the blocks of the original picture is effective for enhancing the transmission efficiency. In addition, as in the foregoing, it is possible to apply the method wherein the values of the matrices (D1 . H1) and (H2 . D2) are computed beforehand, and they are fetched from the transform constant memory 58. Incidentally, as to the aforementioned transmission efficiency, an improvement of about 8% has been expected by a simulation.

Processes conforming to the contents of the above interpolation and filtering processes can be realized through quite similar controls merely by increasing the area of the transform constant memory, so that the method of the embodiment is very flexible.

In this embodiment, the multiplier-accumulator circuits are employed for the operations. However, in the case where the processing period of time has some margin, signal processors can also be utilized.

CLAIMS:

1. A picture coding apparatus in which a picture signal is divided into blocks, a difference signal between the picture signal or a picture signal belonging to the block and a transmitted picture signal is multiplied by a first orthogonal transform matrix so as to be converted into coefficients, and the coefficients have redundancy removed using a variable-length code or the like; wherein in addition to the first orthogonal transform matrix, products between said first orthogonal transform matrix and desired matrices are comprised as a group of second transform matrices, and wherein an orthogonal transform or an inverse transform is performed by properly changing-over said group of second transform matrices, whereupon the transformed signal is transmitted, recorded or reproduced.

2. A picture coding apparatus according to claim 1, wherein products between said first orthogonal transform matrix and products of matrices for picture resolution conversion and image manipulation processes such as expansion, compression and rotation of picture signals, matrices for filtering processes such as low-pass and high-pass filtering processes, or/and matrices of combinations thereof are comprised as said group of second transform matrices.

3. A picture coding apparatus according to claim 1,

wherein the picture signal or the difference signal is properly subjected to any one of a number of filtering processes having different characteristics so that, among the coefficients linearly transformed by the use of any of said second group to transform matrices, ones not to be transmitted may become smaller in absolute values than ones to be transmitted, whereupon the processed signal is transmitted, recorded or reproduced.

4. A picture interpolation circuit comprising means for dividing a picture signal into blocks, and for multiplying matrix-shaped pixel signals belonging to said each block, by each of a first orthogonal transform matrix and a second transposed orthogonal transform matrix from both sides thereof, so as to be transformed into coefficients, and means for multiplying the transform coefficients by products between a third inverse transposed orthogonal transform matrix and a fourth inverse orthogonal transform matrix or between said third matrix and any desired matrix, and products between said fourth matrix and any desired matrix from right and left sides thereof, respectively.

5. A picture interpolation circuit according to claim 4, further comprising means for multiplying said pixel signals from the left side thereof by products among said first orthogonal transform matrix, said fourth inverse orthogonal transform matrix and any desired matrix and means for multiplying said pixel signals from the right side thereof

by products among said second transposed orthogonal transform matrix, said third inverse transposed orthogonal transform matrix and any desired matrix.

6. A picture coding apparatus constructed substantially as herein described with reference to and as illustrated in Figs. 1 to 4 of the accompanying drawings.

7. A picture interpolation circuit constructed substantially as herein described with reference to and as illustrated in Figs. 5 and 6 of the accompanying drawings.